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Improving stroke education with augmented reality: A randomized control trial

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A R T I C L E I N F O

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A B S T R A C T

Stroke is one of the leading contributors to the global burden of disease. The prevalence of stroke increases with age, and with an ageing population, this is expected to place increasing strains on health care teams. Education for diseases such as stroke is vital to enhance patient outcomes and compliance with treatment regimens. This study investigated the effectiveness of augmented reality (AR) compared to a written pamphlet for enhancing the understanding of stroke. 101 participants were randomised into two groups to complete a lesson using either a printed pamphlet ($n = 50$) or AR ($n = 51$) delivery mode. The educational interventions were identical, describing important aspects of stroke physiology and pathophysiology, as well as brain anatomy. Participants answered a pre-test multiple-choice questionnaire to evaluate prior understanding before the lesson, followed by an additional multiple-choice test and Likert-scale survey after its completion. Pre- and post-test scores demonstrated effective learning from both interventions ($p<0.001$), with no significance differences between AR or pamphlet scores. Participants using AR reported more enjoyment using the resource ($P<0.01$), and perceived AR to be a better learning tool ($p<0.001$) with more helpful visualizations ($p<0.01$). Participants using AR reported more favourably that it would help their friends or family to better understand stroke compared to those using the pamphlet intervention ($p<0.001$). Overall, both modes were equally successful for learning with participants perceiving AR as the preferred mode for content delivery. This presents AR as an effective technology to enhance health literacy and comprehension surrounding specific diseases such as stroke.

Introduction

Educational technology has continued to evolve rapidly over the past decade to meet the increasing calls for educators to provide an individualised, student-centred learning experience. Augmented reality (AR) allows participants to interact with virtual models using a smart device, such as a mobile phone or tablet. The merging of real and virtual worlds through AR has the potential to allow individuals to discover abstract theories, phenomena, processes and behaviours as well as features that would typically be unavailable in a traditional classroom setting [21]. This can be further extended to clinical education and the teaching of human anatomy and pathophysiology where multiple studies indicate the success of AR in improving student engagement and lesson enjoyability compared to traditional modes of instruction [2,8,27,29]. Of particular interest are diseases such as stroke, where patient and family education contributes to the success of recovery regimes, as well as the patient's informed choice of treatments and interventions [6].

Stroke is one of the leading causes of death and disability. In the United States, there are around 1 million hospitalisations each year from stroke, with 34% of all admissions being those under the age of 65-years [9]. With the averaged population age increasing in many countries, it is important to ensure the educational tools detailing diseases to patients, friends and their families are evidence-based and effective. Currently, most stroke educational resources are presented as printed pamphlets or booklets, which are heavily reliant upon text-based instruction with 2D illustrations [7]. It is these scenarios in particular, where the use of AR could facilitate a modern, interactive and engaging approach to learning.

Enhancing the provision of health-based educational materials to the community can be of great benefit. Health literacy refers to an individual's ability to comprehend information relating to health [23]. A comprehension of their health issues permits patients to exercise autonomy in their individual health management and encourages modulating behaviours in a way that lead to effective health outcomes [25]. For

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example, in modern clinical environments where shared decision making is commonplace, the ability of a patient to understand their medical condition, such as stroke, may impact their willingness to adopt various treatment interventions. For clinicians, finding the time to educate a patient, their family, and carers about the medical condition, and provide enough information for them to evaluate which treatment will be the most suitable, is difficult in a busy hospital or clinical environment. This means that in some cases, patients may not have sufficient information to manage their health [26]. Using technology can bridge this gap in health literacy, particularly in areas such as stroke, where prior to clinical appointments, or during the recovery phases, a patient can be provided with information through the use of self-directed modes in tablet-based or other technology-enhanced applications [13].

Amongst the various modern modes of technology-enhanced learning, such as virtual reality and mixed reality, AR offers the most affordable and accessible option, as it can be run on the user's smartphone, tablet, laptop or another camera-enabled device, while still providing similar educational benefits to those seen in the other modes [14]. Learning is denoted as a change in the learner's knowledge attributable to experience [16], and the enhanced engagement and interactivity through AR may enhance this process [15]. There is also the potential for AR to enhance overall conceptual knowledge gains, when supplementing other hands-on activities [3]. In 2018 the Australian Bureau of Statistics found that people aged 18–25 years old were the least confident in understanding health information, having only sufficient information to manage their health [1]. As such, this age group provides an ideal candidate-focus for this study in assessing the potential for new delivery modes to improve health literacy. This study aims to assess the effectiveness of AR for delivery of a lesson on the physiology, pathophysiology, and anatomy of stroke.

Materials and methods

This was conducted a randomised controlled trial to assess the impact of presenting information on stroke through an AR application or the identical transcript via a written text-based pamphlet.

Development of the application

A tablet-based lesson on stroke physiology and anatomy utilising AR was created in-house by the corresponding author. This was developed Unity 3D (Unity Technologies, San Francisco, California, USA) using C# coding for interactive elements. The 3D model of the brain was created using 3D Studio Max (Autodesk Inc, San Rafael, California, USA) coloured and labelled, then imported into Unity 3D for display on a Galaxy S3 Tablet (SM-T810, Samsung, South Korea). The AR lesson utilised interactive 3D images of the brain and contained a six-minute audio stream narration with information relating to stroke pathophysiology, brain anatomy and stroke management. Participants held a 6cm-by-6 cm 3D printed cube (Replicator 5, MakerBot Industries, NY), which contained an abstract colour pattern that was different on each side. This pattern was recognised by the device, and when the cube was placed in front of the camera, the screen replaced the cube with an augmented reality as a model of the brain (Fig. 1).While the lesson progressed, the voice-over audio stream was played through headphones, and as the narration progressed, relevant areas discussed were highlighted in a different colour to draw the user's attention. As participants rotated the cube, the 3D model of the brain rotated in real time'. Layers of the brain could be removed via tapping on the screen (Fig. 1). Also, a "dissect" button allowed the removal of layers to see the underlying features. This use of hands, audio and interactive elements was develop to provide an immersive experience for participants.

The pamphlet contained a word-for-word exact replication of the audio transcript from that used in the AR application. Screenshots from the AR application with relevant features highlighted were included in the pamphlet as visual aids. As such, the lesson content was developed to be identical between the AR and pamphlet groups.

Participants

101 Participants aged between 18 and 25 who had no prior formal education on the brain or stroke took part in the study. Participants were recruited by advertising within an Australian University, with most participants being members of the undergraduate student cohort. This project employed a mixed method triangulative, randomised approach. After signing an explanatory statement and providing informed consent, participants were randomised into two groups using the online software (random.org, Randomness and Integrity Services Ltd. Dublin, Ireland). Fifty-one participants were randomised to be in the AR group, with 50 randomised into the pamphlet group. Groups received one of two education interventions containing identical content. The pamphlet group received the information in the form of a printed, written resource containing visual illustrations and text. The AR group received the same content, although this was presented using a six-minute audio stream narration (of an educator reading the same text as the pamphlet) and visual images through AR.

Ethical approval

The study was approved by the Bond University Human Research Ethics Committee (HREC). A provided explanatory statement detailed the project, the required involvement and methods used to maintain confidentiality of the collected data and informed consent were obtained. All procedures followed were in accordance with Bond University institutional and national ethical guidelines.

Reliability and validity

An expert committee was established with five medical academics who had experience teaching anatomy and physiology. This committee evaluated the face value of the survey and established the validity of the questions regarding stroke. The experts assessed each item on the survey to consider their relevance, clarity, format, simplicity, comprehensibility and grammatical construction. The questionnaire was administered by the research assistant, who did not have a role in the teaching of the program, and the survey was written in a way that the participants were able to complete it on their own. Results from the Likert scale survey of participant perceptions returned a Cronbach's alpha of 0.872, demonstrating a good internal consistency. A Kuder-Richardson Reliability Coefficient (KR20) was applied to the MCQ questions and presented a result of 0.609. No participants had any queries or questions for the research assistant regarding the survey after it had commenced.

Statistical analysis

A one-way analysis of covariance (ANCOVA) was used to compare the pre-test and post-test results between students learning from either the pamphlet or augmented reality. Examination of the Shapiro-Wilk statistics and histograms for each group indicated that the use of an ANCOVA was supported. Scatterplots indicated that the relationship between the covariate (pre-test quiz results) was linear to the independent variable. P values of less than 0.05 were considered significant. ANCOVA analysis was performed using SPSS Statistics for Windows, Version 26 (IBM Corp, Armonk, New York, USA)

Likert-scale question responses were checked and confirmed for normality using a D'Agostino and Pearson Normality test. As the Likert-scale responses were determined to be normally distributed, a Student's two-tailed unpaired *t*-test was used to determine significance between data from the AR group to the pamphlet group. P values of less than 0.05 were considered significant. *t*-test analyses were performed using Prism v8 software (GraphPad Software, San Diego, California, USA).

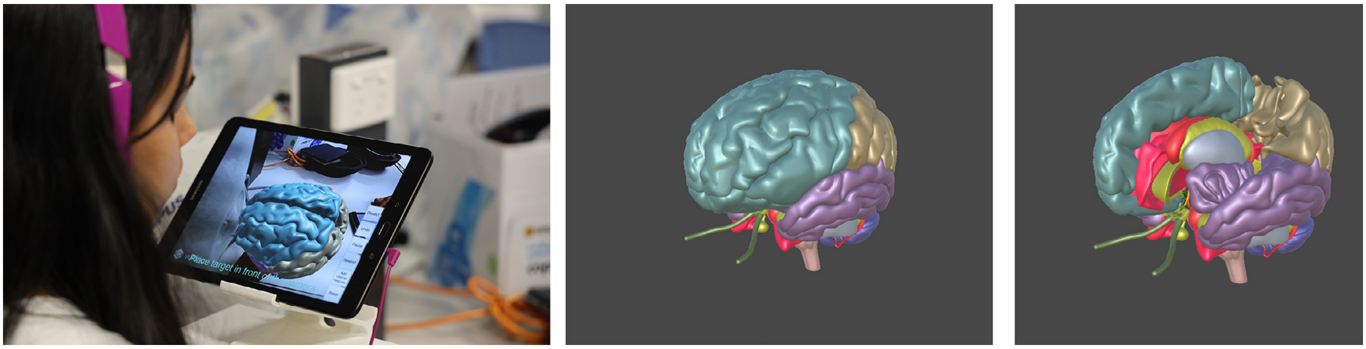

Fig. 1. leftmost image: A participant takes part in the AR application. Middle & Right images: Screenshots of the brain model during development, showing the ability to remove layers.

Knowledge-based performance assessment

Before the educational intervention, participants answered 8 multiple-choice questions (categorised as the "pre-test") to assess their understanding of stroke and brain anatomy. Questions were taken from the content provided in the lesson, providing an insight into the participant's prior knowledge of this area before commencement. Following the intervention (AR or pamphlet), the same 8 questions, identical from the pre-test, were asked again. Following this, an additional 10 multiple choice questions on both direct knowledge and spatial awareness of brain anatomy and physiology was provided. This was used to assess knowledge acquisition after the intervention. Examples of multiple-choice questions included: What is an ischaemic stroke?; what is a haemorrhagic stroke?; which three factors influence stroke recovery?. In addition, questions asked the participant to label areas on a model of the brain, such as the cerebellum, and some asked the user to identify the individual cerebral cortex lobes of the brain.

Participant assessments of the learning mode

After completing the post-intervention multiple-choice based quiz, participants were asked to report their perceptions of the learning mode on a five-point Likert scale, from 'strongly disagree' to 'strongly agree'. Questions were based upon previously-published survey and Likert scale data from recent research in this field [20]. Questions included: I enjoyed using this resource; This resource provided useful information; It is easier to understand anatomy when I can visualise it; This resource was a good learning tool; The instructions and labels were clear; The content was easy to understand; I am more confident in my knowledge about stroke; I am better able to explain stroke to other people; I feel better prepared for learning about stroke in the future; It would help my non-student friends or family to better understand stroke if they used this resource. At the end of the Likert scale assessment, blank spaces were also reserved for any additional written responses the participant might like to include, as well as provide any written feedback for future improvements.

Results

Pre-test

Prior to any interventions all participants completed a pre-test questionnaire containing 8 multiple-choice questions related to stroke and brain anatomy. Participants using the pamphlet obtained a score (mean±SD) of 4.58±1.89 while the AR group obtained 4.53±1.83 (Table 1). There were no significant differences between prior knowledge with responses to each question showing no significant differences. Averaged results for the pre-test also showed no significant differences between either the AR or pamphlet groups.

Table 1
Comparisons in test scores between AR and the Pamphlet intervention. An ANCOVA was applied with $p<0.05$ considered significant.

Tests	p-value
AR Pre-test versus Pamphlet Pre-test	NSD
AR Post-Test versus Pamphlet Post-Test	NSD
AR Pre-Test versus AR Post-Test	<0.001 (***)
Pamphlet Pre-Test versus Pamphlet Post-Test	<0.001 (***)
AR Pre-Test versus Pamphlet Post-Test	NSD
Increase in Score, AR versus Pamphlet	NSD

***$p<0.001$.

Post-test (identical to the pre-test questions)

Immediately after the lesson had completed, both groups completed the same 8-question assessment as the pre-test. On average, participants improved their results from prior, with the pamphlet group receiving 7.08±1.21 ($n=50$, $P<0.001$ compared to pre-test) and AR group receiving 6.94±1.14 ($n=51$, $P<0.001$ compared to pre-test). Both groups improved their exam scores, and there were no significant differences between each of the learning modes.

Post-test (knowledge acquisition assessment)

After the initial pre-test assessment, both groups completed a quiz containing 10 new questions (different to the pre-test) which were derived from the content presented in the intervention. For this test, the pamphlet group received 7.66±1.77 and AR group received 7.38±1.59. There was no significant difference between these scores (Table 1). With all results combined (18 questions after the intervention), the pamphlet group received 14.74±2.6, and the AR group received 14.18±2.37, with no significant differences between either group (Fig. 2, Table 1).

Participant perceptions of the learning mode

After completing the quizzes, participants were provided with a 10-question survey related to their perceptions of the learning mode. Responses were submitted using a Likert-Scale from Strongly Disagree to Strongly Agree for each statement. In each case, AR scored higher than the pamphlet presentation. For 6 of the questions, the higher scores for the AR presentation were significant (Fig. 3). Participants were also provided with blank spaces in order to provide written additional feedback (Table 2).

Responding through the 5-point Likert scale, participants significantly favored the use of AR compared to the pamphlet as the preferred learning tool. The AR group scored significantly higher in the perception that they had become better able to explain stroke to other people

Table 2
Additional written feedback provided by participants.

AR	Pamphlet
I found it a little distracting to hold the cube as it would sometimes the brain would come and then disappear, and this took my focus off the voiceover.	I think the resource was quite useful in helping me understand stroke and the different parts of the brain. At some points, I felt that sentences were slightly long and complicated, which may make it more difficult to be a member of the general public to understand.
Easier to understand using this tool. Could be better with subtitles	It wasn't too engaging kinaesthetically even though it looked aesthetically pleasing.
Hopefully, in the future, models will have more details like blood vessels, and we can use this tool on our own devices.	A summarized version of the detailed notes would be more helpful as reading a lot of pages at once is overwhelming.

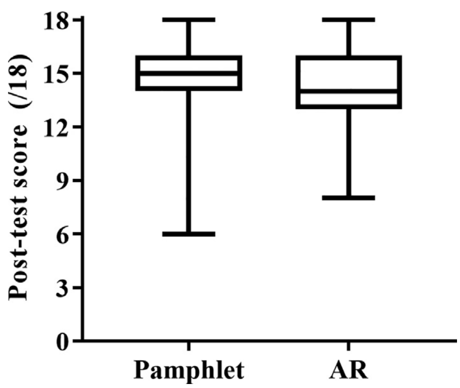

Fig. 2. Pamphlet and AR post-test score variation. Includes both post-tests (18 questions, $n = 101$).

(P<0.01, compared to the pamphlet group's responses); that they found it easier to understand the anatomy (P<0.01); found it more useful compared to the pamphlet group (P<0.05); and enjoyed using the resource more than the pamphlet group (P<0.001). In addition, those using AR, perceived that this mode would help my non-student friends or family to better understand stroke if they used this resource (P<0.001). However, not all results were significant. Both groups agreed that they were more confident in their knowledge of stroke after the lesson (NSD), while both also agreed that the content was easy to understand (NSD) and the instructions and labels were clear (NSD).

Discussion

When presenting information in a health sciences or medical course, educators have a wide variety of modes available to select. This study aimed to assess the effectiveness of AR as a tool to improve health literacy surrounding stroke by examining learning perceptions and knowledge acquisition through using either AR or a pamphlet. Both modes were successful as educational tools with participants achieving significantly higher results in post-intervention assessments. However, as many educational resources surrounding diseases are presented to patients as pamphlets and written text, this study identifies AR as a potentially effectively replacement which can package disease and health information in a contemporary way. Augmented reality may be hugely

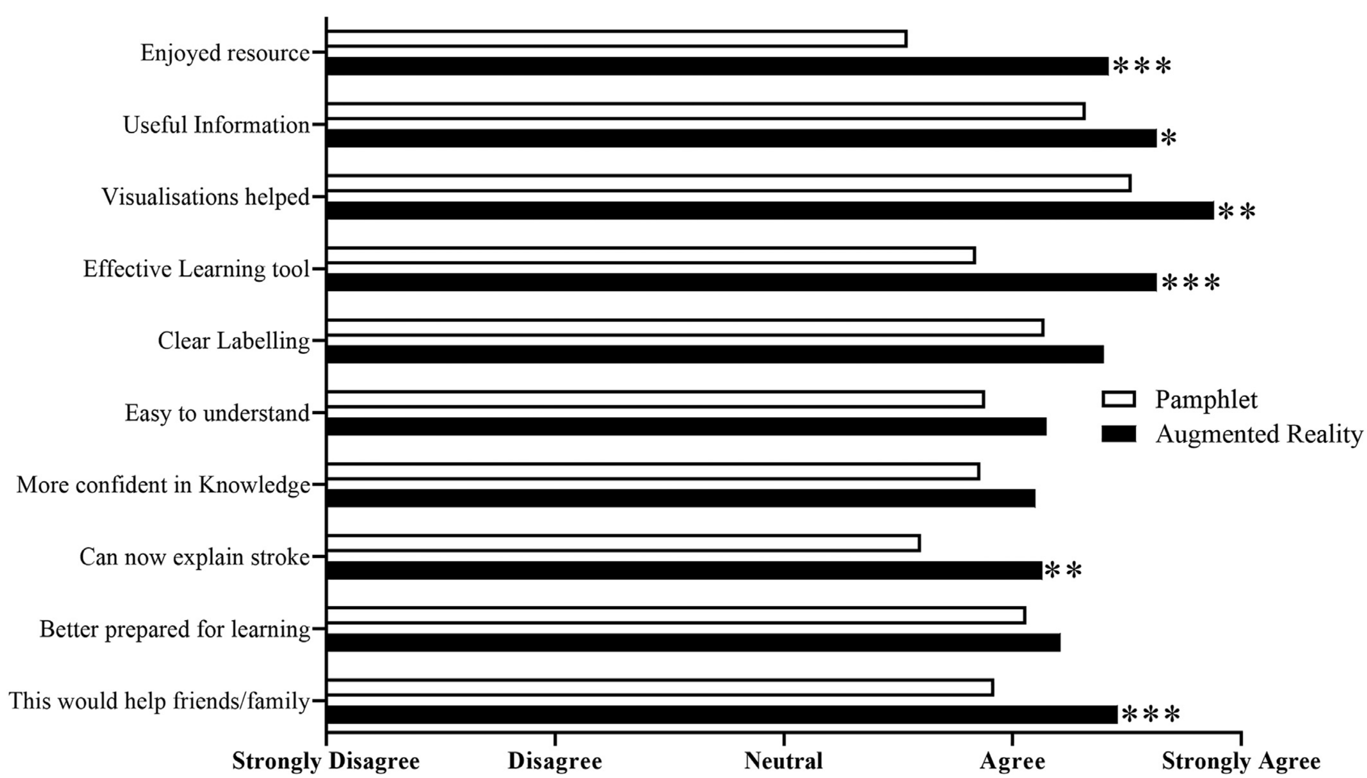

Fig. 3. Participants perceptions based upon Likert-Scale data. $^{*}P$<0.05, $^{**}P$<0.01, $^{***}P$<0.001. Student's two-tailed unpaired t-test.

helpful in such scenarios following its success in medical and health sciences education [2,8,17,27], although not many studies have identified its use in education surrounding a specific pathology such as stroke. Enhanced stroke education might not only assist in patient, family and community understanding, but also help others to identify stroke early and seek medical attention [28]. This study's investigation into the delivery modes of stroke educational material is the first step in preparing quality instruction to assist in clinical and public education for this disease.

This study suggests that AR and pamphlets are equally successful for educational interventions, with both modes resulting in higher participant test results after the intervention. Comparing the two modes, participants in both groups commenced the lesson with a similar background knowledge regarding the brain and stroke, and both groups improved on their test performance to the same degree. Nonetheless, AR was perceived by users to be the superior learning tool for participants and their non-student friends or family, which is consistent with other successes observed from the use of AR in STEM learning [10,11,18].

Augmented reality's contributions to education identify the new potentials offered in teaching and learning. AR offers an affordable and accessible option to facilitate learning, as it can be run on a user's own smartphone, tablet, laptop or other camera-enabled devices, while still providing similar benefits to those seen in other modes. The use of one's hands to hold the 3D printed cube, as well as listening to an audio stream while the screen responds with highlights and interactive elements, helps to create a highly engaging experience for participants. Rather than simply view or read the content, through augmented reality the user can manipulate the model in a self-directed way and take control of their own learning.

Limitations and future directions

Although educating family and friends is an essential aspect of any health education, the primary target audience for stroke education remains the patients, who are predominantly over 60 years old [5,24]. As the participants in this study were 18–25, this may provide limited information on the suitability for AR as an educational intervention in a clinical environment. This limited the overall outcomes of this study, which would benefit from being repeated with an older participant base. In addition, young people may prefer modern technology, and this could further underestimate the effect that a conventional text-based educational approach could bring [19]. The data could also benefit from the survey being repeated on individuals with lowered socioeconomic status, lowered levels of education and health literacy [25]. This is an important target group for health education, as populations with lower educational achievement are more likely to have higher rates of morbidity and mortality as a result of chronic disease [22], and as such, could further benefit from enhancements to educational interventions surrounding specific diseases. In addition, the evidence supports the practice of potentially converting the current pamphlet-based text resources provided to families and carers affected by stroke, into more technology-enhanced curricula. This research also provides evidence for educators wishing to adopt a technology-enhanced approach to stroke education or enhance student of disease using augmented reality.

Conclusions

This study identifies several benefits for using AR to present information on diseases such as stroke. Although there was no specific increase in test scores or learning obtained from AR compared to the pamphlet, participants using AR identified a far greater and improved satisfaction with the resource and perceived an enhanced learning experience. This correlates with the improvements observed in both the university and the schooling system [4,8,12]. AR's enhanced interactivity, engagement and positive participant perceptions suggests this is an effective self-directed learning mode compared to more traditional resources. Based upon its potential, we hypothesised that the use of AR would facilitate learning at a higher level when compared to simple text-based pamphlets. Although this was not supported by the results, the higher participant perceptions of AR as a delivery mode may facilitate retention of learned content due to an enhanced enjoyment when engaging with the learning content. To investigate this further, future studies could assess if there are any benefits to the long-term recall of the newly acquired knowledge. This study is the first to examine the use of augmented reality to detail the mechanisms underlying a specific disease, and although stroke was the focus, the findings will likely relate to other diseases and disorders. As such, AR demonstrates excellent potential for improving health literacy and patient outcomes by enhancing education in common disorders and clinical presentations.

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None.

Disclosures

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Declaration of Comepting Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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